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sustaining the testimony of the workman is of the most convincing character. The passage from the yellow till into the blue till and the occurrence of occasional strata of gravel are characteristic of the glacial deposits of northern Ohio. The implement had been subjected to oxydizing agencies characteristic of the deeply covered strata of that immediate vicinity. It is impossible briefly to detail this evidence. We must therefore wait for its full publication by Professor Claypole.

In a word, the geological situation at New London, Ohio, is this: The watershed between the Great Lakes and the Ohio is but a few miles to the south, and drains to the north through the main valley of Vermillion River. The land about New London is level for several miles, and is about two hundred feet below the summit of the watershed. There is no opportunity for any disturbances to have occurred subsequent to the glacial period; but in the retreat of the ice from the watershed a temporary glacial lake doubtless occupied the upper part of the valley of Vermillion River, emptying its waters into a tributary of the Mohican, and thence into the Muskingum and the Ohio. But this lake evidently did not exist for a great length of time.

Heretofore numerous flying reports of the discovery of implements in the glacial till have been made, but this is the first instance where the evidence has seemed in itself altogether convincing and satisfactory.

RELATIVE EFFICIENCY OF ANIMALS AS MACHINES.¹

BY MANLY MILES, LANSING, MICH.

In my paper on Energy as a Factor in Rural Economy, read at the Washington meeting of the Association, approximate quantitative estimates were made of the energy expended

¹ Read in Section F. at the Buffalo meeting of the American Association of Science, Aug., 1896.

in the exhalation of water by plants, and evaporation from the soil; and at the Madison meeting similar estimates were given of the potential energy of an acre of corn, and of a fat ox, as representing the work done in the constructive processes of growth. The substance of the last mentioned paper, with some additional matter was published in the *AMERICAN NATURALIST* of July, 1894.

Some further illustrations of the same general principles are now presented in an inquiry as to the relative efficiency of different classes of animals, as machines, in utilizing the potential energy of their food in useful work.

From the imperfect data now available, there are many questions relating to this subject that cannot be definitely answered, but the approximate quantitative estimates we are able to make must be of interest in suggesting the lines of research required for a satisfactory solution of the problems involved in discussing the economy of foods and diets, and especially in the interpretation of the results of feeding experiments.

The chemical theories of nutrition have been so generally accepted in popular expositions of alimentary processes that it may be well to recapitulate the leading facts relating to energy as a factor in physiology in order to clear up the field of view and give due prominence to the principles we have to deal with.

The food consumed by animals serves two distinct purposes which should be clearly distinguished. The materials required in building tissues, and in the manufacture of animal products (meat, milk, wool, etc.), have alone been noticed in popular essays on the subject of nutrition, while the quite as important expenditures of the energy supplied in foods, as the motive power required in the constructive processes involved in converting the food constituents into animal tissues and products, have been misinterpreted or entirely ignored.

As pointed out in the papers above noticed, but a limited amount of the constituents of foods are stored up by animals in their processes of growth—in their increase when fattened—or in the animal products they manufacture. With refer-

ence to our present subject, the following table, showing the percentage of food constituents found in the increase of fattening animals at Rothamsted, will serve as a sufficient illustration.

TABLE 1.

Percentage of food constituents in the increase of fattening animals.

Constituents of Food.	Stored in Increase.		
	Oxen.	Sheep.	Pigs.
	Per cent.	Per cent.	Per cent.
Proteids	4.1	4.2	13.5
Carbo-hydrates and fat	7.2	9.4	18.5
Ash	1.9	3.1	7.3
Dry Substance	6.2	8.0	17.6

It will be seen that much the larger part of the food constituents were not utilized by the animals as materials for building tissues, but they have served a useful purpose in yielding up more or less of their stored energy, according to the degree of disintegration to which they were subjected, which was made available in the constructive processes of nutrition and the related incidental physiological activities of the system.

With this limited demand for the constituents of foods to serve as materials for tissue building, there must be an extensive disintegration of their organic substance to furnish the enormous supplies of energy required in the repair of tissues, in increase in growth, in the vaporization of water exhaled by the lungs and skin, and to supply the sensible residue that is lost by constant radiation from the body in the form of animal heat.

The obsolete theory of Liebig that certain food constituents are alone used to build tissues and that certain other constituents are burned in the system to produce heat, still continues to be the leading assumption in attempts to popularize chemical theories of nutrition in formulating diets and nutritive

ratios, and attention should be directed to the erroneous interpretations of organic processes that are made in the application of this false theory in connection with a fancied analogy of the animal machine to a steam engine.

We are told that "when coal is burned in the furnace a part of its potential energy is transformed into the mechanical power which the engine uses for its work. The rest is changed to heat which the engine does not utilize, and which, therefore, is wasted. The potential energy of the food is transformed in the body into *heat* and *mechanical power*. *The heat is used to keep the body warm. The mechanical power is employed for muscular work.*"

As an outcome of this false analogy the term "fuel value of foods" has been introduced to serve as an index of their capacity "to keep the body warm," and provide for muscular work. The absurdity of these crude and superficial views of energy as a factor in nutrition will be readily recognized by physiologists and we need only notice some obvious inaccuracies of statement.

In the first place, there are no processes of combustion in physiological activities, and fuel as such, can have no value in animal nutrition. The assumption that the potential energy of foods not expended in muscular work is "used to keep the body warm," is in direct conflict with familiar physiological activities. There are large expenditures of energy in transforming to the form of vapor the water exhaled by the lungs and thrown off as perspiration by the skin and it is a well known fact in physiology that the body is cooled by the evaporation of water from the surface that is constantly taking place.

The laboring man, perspiring freely in hot weather, expends a considerable part of the potential energy of his food in the cooling process of vaporizing the water discharged by the skin as a result of his exertions. The law of the conservation of energy is strictly observed and there is no demand for fuel to burn to "keep the body warm." The heat liberated in the destructive metabolism of the tissues, or what we speak of as the wear and tear of the system, is disposed of in various ways,

and the large expenditure in the cooling machinery for vaporizing water is an important factor in securing a proper adjustment in equilibrium of the numerous physiological activities of the system.

The fallacious and misleading theories of nutrition we have noticed have been so widely disseminated in recent official reports and bulletins that a detailed statement of the role of energy in animal nutrition, as now recognized by physiologists, seems to be required in relation to our present subject.

The energy required as the motive power in building tissues and the elaboration of animal products, as well as that expended in muscular work, is all derived primarily from the potential energy of the organic substances consumed as food, and as an incident of the various metabolic processes of the system animal heat is produced.

The stored, or potential, energy of organic substances is an essential element of their constitution, representing the work done in their processes of construction, and it can be liberated in the form of heat by any of the various methods of disintegration to which they may be subjected. For example, when organic substances are burned the heat produced is a measure of the energy stored up in their construction, but this method of liberating heat from food constituents has no place in physiological processes, and the value of foods as fuel is not a legitimate subject of discussion in domestic economy.

Microbes disintegrate the organic substances on which they feed and liberate their stored energy in the form of heat, as in the familiar processes of fermentation. The numerous microbes in the alimentary canal add their quota to the available energy in the form of heat derived from the constituents of foods which they tear apart in feeding upon them. The digestion of foods by animals is another means of liberating the stored energy in the form of heat.

Destructive metabolism, resulting from the various activities of the animal machine, immediately follows the constructive processes and the stored energy of the tissues originally derived from food constituents is liberated as heat which, so

far as needed, is used again as the motive power in rebuilding the disintegrated tissues and other physiological processes.

Animal heat is, therefore, the result of physiological activities that are carried on in accordance with the laws of the conservation of energy, without the slightest indication of anything analogous to processes of combustion.

Living substance, as pointed out by Foster, is matter constantly undergoing change, energy being used and stored up in constructive metabolism, and liberated again as heat in the correlated and quite as essential processes of destructive metabolism. Energy doing work, or stored as potential energy in the tissues, cannot be detected by the thermometer, and the heat liberated from foods in the various processes of disintegration they undergo, and from the tissues through destructive metabolism, is again made latent, as far as it is utilized in doing the work required in constructive metabolism, in vaporizing water exhaled by the lungs or thrown off by the skin as perspiration, and animal heat is the sensible residue not disposed of in these physiological processes.

Our domestic animals may then be looked upon as machines for doing work in the repairs and other vital activities of the animal machine itself, including muscular exercise, and the manufacture of animal products used as food by man. The importance of these animal machines as factors in domestic economy leads us to inquire as to their relative efficiency in utilizing the potential energy of foods in the special work they are fitted to perform.

Aside from the individual and class peculiarities that require attention, their efficiency in utilizing energy must vary with the quality and quantity of food consumed and a tentative solution of the problems presented in this line of inquiry can only be made. The quantitative estimates of the expenditures of energy in different ways we are able to make must, therefore, be interpreted as representing approximately the results with the particular animals under the conditions to which they were subjected.

The feeding experiments at Rothamsted, and the composition of different animals and their increase, as shown in the

extensive series of analyses made there, furnish the most convenient and only reliable data for our purpose in the case of fattening animals. The average results with oxen, sheep and pigs, as estimated by Sir John Lawes several years ago, and the feed consumed and increase made by the "analyzed fat pig" have been taken as the basis for calculating the expenditures of energy as given in the following tables.

In making a comparable estimate of the expenditures of energy in milk production, the record of a Guernsey cow at the New York experiment station in 1891, appeared to answer the required conditions, as detailed statements of the composition of the food consumed and milk produced were given, and the dry substance of the milk for each month differed but little from the dry substance of the 100 pounds of increase in the fattening animals under consideration, indicating in a general way that nearly the same amount of work had been required in its production.

The factors used in estimating the potential energy of organic substances (based on experiments of Berthelot and

TABLE 2.

Expenditures of energy in fattening oxen, sheep and pigs, to produce 100 pounds of increase in live weight; and a similar estimate of the expenditures of energy in milk production. In foot-tons of work.

	Potential energy of total feed consumed.	Expended and stored in 100 lbs. of increase.	Lost in excreta including urea.	In repairs of the system and other physiological processes.
Oxen	3,389,929	413,558	955,790	2,020,580
Sheep	2,809,787	440,584	655,967	1,713,240
Pigs	1,269,181	457,800	175,674	635,699
"Analysed fat pig"	1,478,393	435,160	272,335	770,900
		In 557 lbs. milk.		
Guernsey } April	1,610,800	329,390	581,573	699,840
Cow } In 581 lbs. milk.				
} May	1,626,678	349,440	564,020	713,230

Andre, 1890) represent in round numbers the calories per pound of the proximate principles of foods and tissues as follows: proteids, 2500 calories; fats, 4200 calories; and carbohydrates, 1900 calories.

For convenience of comparison, the energy in the table is represented in its equivalent of foot-tons of work; the energy expended in raising a weight of one ton one foot.

Without an examination of other details this table would be misleading in its indications of the relative efficiency of the different classes of animals as machines for doing work. There are decided differences in the quality and quantity of feed consumed which should be taken into consideration, but we have no data for a quantitative estimate of the modifying influence of these different conditions which can only be noticed in general terms. For convenience of comparison the most important facts relating to feed consumed may be summarized in tabular form.

TABLE 3.

Kind and quantity of feed consumed by fattening animals to produce 100 pounds of increase in live weight, and feed of the cow for equivalent results in milk production.

	Dry substance of feed.	Dry substance of increase.	Proteids in feed.	Proteids in increase.	Feed Consumed.		
					Hay.	Grain.	Green feed.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Oxen	1109	68.6	218	9	600 (clover)	250 (oil cake)	3500 (swedes)
Sheep	912	72.5	177	7.5	300 (clover)	250 (oil cake)	4000 (swedes)
Pigs	420	73.8	52	7.0		500 (Barley meal.)	
" Analyzed fat pig "	478	71.4	100	7.7		1. Bran. 2. Bean and lentil meal. 3. Barley meal.	
Guernsey } April	469	78	82	19.2	300 } (clover and	210 } mixed	420 } corn
Cow } May	510	83	81	21.5	182 } timothy)	213 } grain	868 } ensilage

To produce 100 pounds increase the oxen consumed more dry substance of food than the sheep, and of coarse fodder there was twice as much hay requiring a larger expenditure of energy to dispose of it, and a smaller amount was utilized and stored in the increase which contained less dry substance. There was also a larger loss in the excreta and a greater expenditure in repairs of the system and other physiological processes, resulting from the increased metabolism.

A comparison of tables 2 and 3 will show that less work is required to dispose of the smaller amount of coarse feed in the rations of the sheep, and with less dry substance of feed they give a much better proportionate return in increase than the oxen; while the pigs fed on barley meal alone make the same increase from less than one-half the dry substance of feed consumed by the sheep, with a diminished waste in excreta, and the repairs of the system and other physiological processes are carried on with a comparatively small expenditure of energy.

The fourth column of table 3 is, however, of special interest in relation to the processes of nutrition, and the difference in the results we have been discussing. One of the most marked results of proteid substances in the food, now recognized by physiologists, is to increase the metabolism of the system. From the small amount of proteid substance stored up in the increase of fattening animals, as shown in tables 1 and 3, an active metabolism of the system must be carried on to dispose of any considerable excess supplied in the food, as all that is digested and not retained in the increase is discharged by the kidneys in the form urea. The supply of energy to carry on the increased metabolism of the system arising from an excess of proteid food is, to some extent, however, immediately provided for in the heat liberated in its conversion into urea.

The oxen, with 218 pounds of proteids in their feed, give the smallest return in increase, the largest amount of waste in excreta, and decidedly more work is required in repairs of the system and other physiological processes resulting from the increased metabolism. The pigs fed on barley meal, with only

one-fourth as much proteid matter in their feed, have a decided advantage in utilizing energy in their increase, with less waste in excreta, and a comparatively small expenditure of energy is required to keep the machine in working order.

A comparison of the results with the pigs fed on barley meal and the "analyzed fat pig" with a highly nitrogenous diet, will furnish quite as striking an illustration of the influence of proteid food, as the conditions are less complex from the absence of coarse fodder in the rations.

The "analyzed fat pig" consumed more dry substance, and nearly twice as much proteid matter, to make 100 pounds increase in live weight as the pigs fed on barley meal alone, but less energy was utilized in its increase, containing less dry substance and decidedly more was lost in excreta and a larger amount was required in repairs of the system.

TABLE 4.

The energy of food consumed by different animals to produce a given increase is expended as follows, under conditions above noticed.

	In increase.	Lost in excreta.	In repairs and other physiological processes.
	Per cent.	Per cent.	Per cent.
Oxen	12	28	60
Sheep	16	23	61
Pigs	36	14	50
"Analyzed fat pig"	29	18	52
Guernsey { April	20	36	43
Cow { May	21	35	44

The pigs fed on barley meal with their comparatively simple organs of nutrition, require less dry substance of feed and less energy to make a given increase than the ruminants with their complex nutritive machinery and large amount of coarse fodder in their rations which they are fitted to utilize; but pigs and ruminants are alike in failing to give as large returns in profitable increase with an excess of proteids in their feed.

The results recorded in table 2 must then be attributed to differences in the working machinery of the animals themselves, and the modifying conditions of the relative amount of coarse fodder and proteids in the feed consumed, but with our present knowledge of vital activities the relative influence of these variable factors cannot be determined.

The expenditures of energy by different animals in different ways, given in table 2 in foot tons of work, are summarized in percentages of the energy of feed consumed in the following table for convenience of comparison.

In the last columns of tables 2 and 4, several well defined physiological processes are grouped together from the lack of data to discriminate between them, and they undoubtedly vary in the relative expenditures of energy required in them under different conditions. Without attempting an exhaustive enumeration of these processes, the following may be noticed as of the first importance from the work performed in their activities.

Constructive metabolism in the repair of tissues; vaporization of water exhaled by the lungs and skin; work of the involuntary muscles in respiration and circulation of the blood; energy expended in mental activities and the functions of secretion and excretion; loss of heat by radiation from the body; and work done by the voluntary muscles.

It will be seen from table 4 that the largest percentage of the available energy of foods is expended in these strictly physiological processes concerned in maintaining the integrity of the animal machine. Under the conditions of feeding experiments, with fattening animals and cows giving milk, but little mechanical work is done by the voluntary muscles, and the last item of our enumeration of physiological processes might have been omitted as insignificant in relation to the enormous expenditures of energy in the other normal activities of the system to which attention has been directed.

If mechanical work is done by animals, it must be at the expense of the energy that might, under other conditions, be expended in the manufacture of animal products, as the physiological processes enumerated above must all be provided for

in fattening animals and cows giving milk with a minimum of muscular exercise, as well as in the case of animals engaged in severe muscular work.

The energy expended in mental activities is of the first importance in its influence on the efficiency of the animal machine in useful work. The nervous system, through which mental endowments are manifest, has intimate relations with every part of the animal machine and the direction in which energy is expended is largely determined through its agency.

Practical farmers are well aware that animals fail to give profitable returns for feed consumed when restless and excited through any source of disturbance, or when dissatisfied with their feed and surroundings.

The available energy of a liberal supply of nutritious food may all be expended, and even the stored energy of the tissues drawn upon to carry on the increased physiological activities resulting from mental and nervous derangements of the nutritive machinery without any expenditure in profitable production. In conducting feeding experiments and in the interpretation of their results this is one of the most difficult factors to deal with, as it may have a dominant influence on the final outcome.

The approximate estimates of the relative efficiency of different animals in utilizing the potential energy of their feed in useful work, which have been given in mere outline, will require revision and correction as we become better acquainted with the specific influence of the variable factors of food and environment on the work performed by animal machines. Even in their present imperfect form they may, however, serve to illustrate the significance of energy as a factor in animal nutrition and the futility of formulating diets and nutritive ratios in terms of their chemical constituents.